Spatial Patterns of Chinook Salmon Spawning in Relation to the Spatial Organization of Riverine Habitats and Core Areas

Chapter 3

Development of Salmonid Conservation Strategies
Phase I, Project No T01426T

Presented to:

King County
Water & Land Resources Division
201 South Jackson Street, Suite 600
Seattle, Washington 98104-3855

Prepared by:

Douglas Martin
Martin Environmental
2103 North 62nd Street
Seattle, Washington 98103

and

Lee Benda
Earth Systems Institute
3040 NW 57th Street
Seattle, Washington 98107

February 6, 2004

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF TABLES

INTRODUCTION

In Chapter 1 we proposed that core areas are the habitats that functionally control population spatial structure. We define population spatial structure as the spatial/temporal distribution of individuals in the population and the demographic processes that generate that distribution. Spatial structure is important because it helps managers to define the boundaries and conservation status of distinct population units as well as the locations of habitats associated with these units. Spatial structure influences population extinction risk (Hanski and Gilpin 1991, Tilman and Lehman 1997, Cooper and Mangel 1999) and is believed to be an essential attribute of a viable salmonid population (VSP; McElhany et al. 2000). In Chapter 1 we discuss how population spatial structure is a consequence of population demographic processes that operate within and are constrained by habitat spatial organization and temporal disturbance patterns. We hypothesize that spatial structure is reflective of the systematic influence of homing to certain habitats that maximize survival. This is supported by the premise that certain habitats that consistently support high densities over time delineate patches that are biologically suitable and are persistent over multiple generations. These habitats (i.e., core areas) functionally control population spatial structure by defining the location of population nodes within a river network, and second by defining the locations of population migration and dispersal corridors. The location of population nodes and the associated corridor then define proximity or probable areas of population dispersal.

In Chapter 2 we identify and describe the landscape sources and mechanisms that underlie the non-uniform distribution of habitat patches in river. We explore how the scale of variation in river morphology (i.e., size and separation distance of habitat patches) scale with size of rivers and vary within and across watersheds. We discussed the role of watershed disturbances (i.e., fires, storms, floods, erosion) in contributing to the non-uniform distribution of riverine habitats.

Given this framework we make the following predictions about Chinook spawning habitat and core areas:

1. Chinook salmon spawning habitat (i.e., their core areas) will be spatially discontinuous across a range of scales (kilometer to meter).

2. The size and spatial scale of variation in locations of Chinook spawning habitat (i.e., the distance separating patches, Chapter 2, Figure 1) are dictated by seven habitat forming processes:

   - Network geometry via populations of tributary confluences.
   - Topographic variations in valley widths leading to alternating canyons and floodplain segments.
   - Landslides and rockfalls.
   - Bedrock outcrops.
   - Log jams.
   - Channel meanders.
   - Boulder steps.

3. The spatial scale of variation in Chinook spawning habitat will vary across rivers as a function of differences in basin size, basin topography, and river network geometry, as well as variation in sediment transport and storage related to dams and waterfalls.

4. Habitat patch size among rivers will vary in relation to the relative importance of the seven habitat forming processes and the spatial scale of variation among the habitat patches (i.e., habitat patch size associated with alternating pools and riffles will be smaller than those associated with large confluences). Moreover, finer scale habitats (i.e., channel meanders or log jams) are embedded in larger patches leading to a spatial hierarchy of salmon habitats

In this chapter we compare the predicted spatial organization of riverine habitats to the actual distribution of spawning habitats for Chinook salmon in the Skykomish, Snoqualmie, Cedar, and Green rivers. We use the geomorphic framework described in Chapter 2 to make these predictions, and we use existing redd survey data to examine the spatial distribution and characteristics of spawning patches. Based on these findings, we identify the characteristics and probable locations of Chinook salmon core areas for spawning in the four study rivers.

We focused our analysis on the mainstem portion of each river and on the effects of large-scale features (e.g., tributary confluences, variations in valley segments, landslides, and rockfalls) on the spatial organization and characteristics of habitat patches. We recognize that spawning habitats are organized at smaller scales (e.g., pool-riffle, meander, log jams); however, spatial resolution of the analysis was limited by the available data. Our analysis relies heavily on remote sensed data (i.e., DEMs, maps, and aerial photographs) and existing redd survey information that was collected at a coarse scale. Spawning habitat in tributaries was excluded from the analysis because data on redd distribution were inadequate (e.g., survey segments were too long to delineate spatial patterns or annual surveys were inconsistent).

MATERIALS AND METHODS

STUDY RIVERS

The Skykomish, Snoqualmie, Cedar, and Green rivers originate in the Cascade Mountains of Washington and flow westward into Puget Sound (Figure 1). All four river basins have rain and rain-on-snow dominated hydrology. The headwaters are formed in steep bedrock controlled channels that are shaped by a long history of tectonic, volcanic, and glacial processes. These processes also influenced the formation of lowland rivers; however, the recent advance and retreat of the glacial ice sheet during the Vashon period (16,000 years ago) was the dominant process that shaped the lowland topography of the Puget Basin, through which all the rivers flow (Booth et al. 2003).

The study basins have a temperate marine climate with cool wet winters and warm dry summers (Kerwin 2001, Kerwin and Nelson 2001, and Haring 2002). Precipitation ranges from 35 in/yr in the lowlands to 180 in/yr in the highlands. Stream flows in the mainstem rivers are high during the fall-winter storm period (November to January) and during the spring snowmelt period (May to June). The mountain snowpack has a strong influence on summer low flows. The annual low flow period typically occurs during August after snowmelt waters have ended and when precipitation is sparse. Stream flow in the lowland tributaries is dominated by the rain cycle; flows are high during fall-winter and low during the late summer.

Each river supports a native independent population of summer/fall run Chinook salmon (Puget Sound Technical Recovery Team 2001, Washington Department of Fisheries et al. 1993). Spawning primarily occurs from September through October in the mainstem and tributaries. The natural spawning population in each river may include a mixture of wild (i.e., spawned naturally) and hatchery production; however, wild production is dominant in the mainstem study areas of all but the Green River[1] (Haring 2002, Kerwin 2001, Kerwin and Nelson 2001). Salmon hatcheries are located on the Wallace River (tributary to Skykomish River), Issaquah Creek (tributary to the Lake Washington system with the Cedar River), and Big Soos Creek (tributary to Green River). Hatchery Chinook yearlings are also released from Icy Creek (tributary to the Green River at river mile [RM] 48.4). Water diversion dams limit anadromous fish distribution in the mainstem Cedar and Green rivers, and waterfalls form natural barriers to fish distribution in the mainstem Skykomish and Snoqualmie rivers (Figure 1). In the Skykomish and Green rivers, Chinook salmon occur upstream of the fish barriers as a result of adult transplants and hatchery juvenile out-plants.

Land use is similar in all four basins. The lowlands are dominated by a combination of residential, commercial, and industrial uses within the major cities (Seattle, Tacoma, and Everett). Outside of the cities, land use is dominated by agriculture and rural residential development in the lowlands and by forestry in the uplands. Levees and revetments influence channel morphology in the lower urban portions of all four rivers, and dams have altered flows and sediment transport in the Cedar and Green rivers.

---

[1] Recovery of coded wire tags from adult carcasses on spawning grounds indicate that on average 55% of natural spawners are from hatchery offspring (Unpublished data from Tom Cropp, Washington Department of Fish and Wildlife, personal communication, 6/16/03).

Study Area

WASHINGTON STATE

Possession Sound

Lake Stevens

Pilchuck River

Sultan River

Spada Lake

Wallace River

Skykomish River

North Fork

Beckler River

Skykomish River

Snohomish River

Sunset Falls

South Fork Skykomish River

SNOHOMISH CO.
KING CO.

Tye River

Miller River

Foss River

Puget Sound

Tolt-Seattle Water Supply Reservoir

Tolt Dam

Snoqualmie River

Tolt River

WRIA 7

Elliott Bay

Lake Washington

Lake Sammamish

Duwamish River

Snoqualmie River

Raging River

Snoqualmie Falls

North Fork Snoqualmie River

Taylor River

Middle Fork Snoqualmie River

Middle Fork Snoqualmie

Puget Sound

WRIA 8

Cedar River

Chester Morse Lake

South Fork Snoqualmie

KING CO.
PIERCE CO.

Landsburg Dam

Tacoma Headworks

Green River

WRIA 9

Howard Hanson Reservoir

Howard Hanson Dam

Green River

Figure 1

Location of study reaches and Chinook salmon distribution in the Skykomish, Snoqualmie, Cedar and Green Rivers

0 2 4 6 Miles

October 2003

Chinook known to be present in WRIAS 7, 8 and 9 by first-hand information

River/stream

King County boundary

WRIA boundary

Study reaches

Lake

RIVERINE PHYSICAL FEATURES

The geomorphic framework described in Chapter 2 was used in conjunction with a channel network model and digital elevation data (DEMs) to predict certain characteristics of the spatial organization of riverine habitats in the lower mainstems of the Snoqualmie, Skykomish, Green, and Cedar rivers. The network model (Earth Systems Institute [ESI] 2002) predicted the location of channel gradients, valley widths (i.e., alternating canyon and floodplain segments), and geomorphically significant tributary junctions. Existing studies within the various river basins and limited aerial photograph interpretation were used to identify variations in sediment supply, channel gradient and substrate size, locations of significant landslides and rockfalls, and history of channel changes. In combination, modeling and existing studies were used to develop predictions on the sources and spatial scale of variation in Chinook spawning habitat in the four rivers.

The probability of observing significant tributary-junction-related changes in mainstem channels (i.e., changes in channel gradient, particle size, and channel form, etc.) varies with the size of the tributary relative to the mainstem. A logistic regression equation (Chapter 2, Figure 5) was used to predict the probability of undifferentiated confluence effects (based on the ratio of tributary to mainstem drainage areas) in the four Puget Sound Rivers.

The location of alternating canyons (constrained) versus floodplain segments (unconstrained) was predicted using the network model (ESI 2002) at an elevation above the valley floor equivalent to approximately 20X bankfull height. Bankfull height is assumed to be approximately 2 m at the heads of the analyzed segments and to follow a function relating bankfull height to drainage area contained in the model (ESI 2002).

CHINOOK SALMON REDD DISTRIBUTION AND ABUNDANCE

Data

The Chinook salmon redd distribution and abundance data were derived from annual population monitoring surveys that are routinely performed by local resource management agencies. The Washington Department of Fish and Wildlife (WDFW; Tom Cropp, Mike Chamblin, and Curt Kramer, personal communications) provided data for the Skykomish, Snoqualmie, and Green rivers, and Seattle Public Utilities provided data for the Cedar River (Burton 2002, Burton et al. 2003). The duration of the data record, the length of surveys in the mainstem and tributaries, and the length of survey segments within each water body varied by river and over time. The mainstem channels for each river had more comprehensive data than did the tributaries, including record duration and spatial resolution. Longer periods of record are desirable for evaluating temporal consistency of spatial patterns and spatial resolution increases as segment lengths decline. Therefore, given the data available, we focused our analysis on the mainstem channels, and we only included years for which data were recorded for multiple survey segments (Appendix A). We found that the Skykomish and Snoqualmie rivers had the longest data record, but the spatial resolution was limited by relatively long survey segments of unequal lengths (Table 1). Spatial resolution was much better in the Green and Cedar rivers (i.e., relatively short survey segments), but these data were only recorded for the past several years. Older data were available for both of these rivers but were not used because the spatial resolution was poor.

Table 1.   Characteristics of the redd survey data used in this analysis.

River	Period of Record	Survey Reach (RM)	Range of Segment Lengths (mi)	Minimum No. Segments Surveyed per Year	Maximum No. Segments Surveyed per Year
Skykomish	1956 - 1998	12.3 - 51.5	1.9 – 15.2	3	8
Snoqualmie	1954 - 2002	20.5 - 39.6	1.9 – 6.8	2	4
Cedar	1999 - 2002	0 - 21.8	0.8 – 1.0	22	22
Green	1999 - 2002	25.4 - 61.0	0.2 – 5.1	33	33

The starting and ending locations for some of the redd survey segments were adjusted to a common point to facilitate the analysis. The management agencies reported survey segment location in RMs that were derived from maps in the Washington Stream Catalog (Williams et al. 1975). Because spawner surveys were conducted by different people over time and the segment locations (RMs) were interpolated from maps, the recorded starting and ending points often varied by several tenths of a mile. The surveyors generally used the same land features (e.g., bridges, tributary junctions) to delineate the actual starting and ending points of a survey segment (Curt Kramer, WDFW, personal communication, 6/23/03). Therefore, we adjusted the locations for all segments to the RMs that were reported most often in the data record.

In the Green River, redd counts for the longest survey segment (i.e., RM 48.3 to 57.5) were subdivided into three shorter segments (i.e., RMs 48.3 to 51.0, 51.0 to 56.1, and 56.1 to 57.5) using empirical data on redd distribution. Redd counts that were recorded each year during the peak spawning period in each sub-segment were used to calculate the proportional distribution of redds within the long segment (Tom Cropp, WDFW, personal communication, 5/15/03). These proportions were then applied to the total redd counts from the long segment to estimate the number of redds within each sub-segment.

A standardized redd density (SRD) was computed for each survey segment for a given year. Because the survey segment lengths were unequal and the total number of spawning Chinook varied over time, a relative index of abundance was required for the delineation and comparison of redd spatial patterns. The SRD was computed by dividing the redd density (i.e., redds per mile) for each survey segment by the total number of redds in all segments for a given year.

Analysis

We used a "nearest neighbor" type analysis (Benda et al. 2003) to examine the association between spatial patterns of redd density and the spatial configuration of physical riverine features (e.g., tributary junctions, landslides, fish barriers). The strength of association between riverine features and the spatial patterns of redd abundance was determined from the relationship between the SRD for a given survey segment and the distance to the nearest riverine feature. Distances between river features and survey segments were determined from the center of each survey segment to the nearest river feature that occurred either upstream or downstream of the given segment (Figure 2). Distances upstream to physical features were not differentiated from distances downstream because several of the features could impact habitat in both directions, such as tributary confluences and landslides (see Chapter 2). Plots of distance to the nearest river

feature and redd density for each segment showed which river features were more closely associated with segments with high redd density
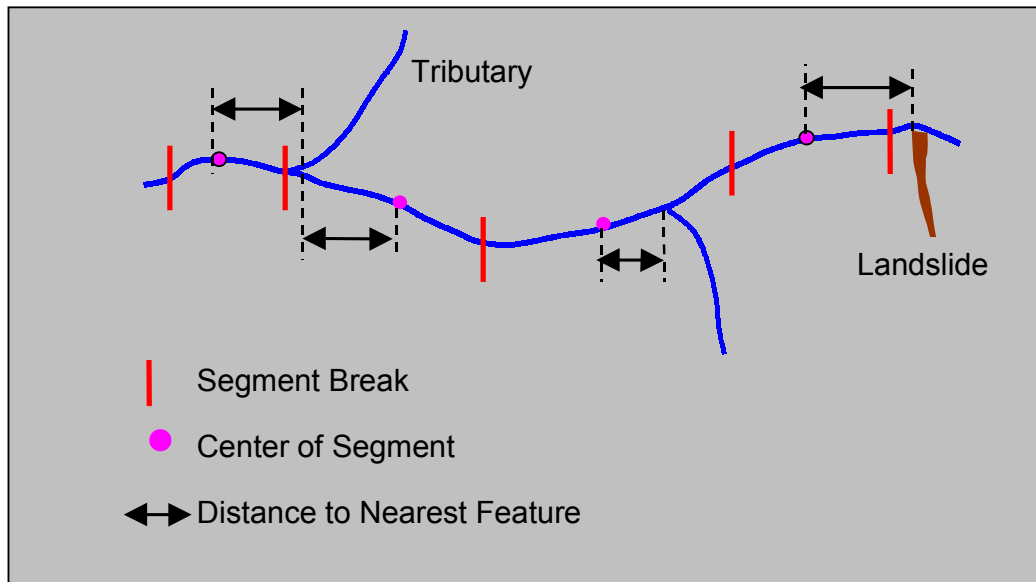

Figure 2.   Schematic illustrating where measurements were taken to determine distance from the center of each survey segment to the nearest river feature.

A one-way analysis of variance (ANOVA) was performed to test for differences in mean SRD among three distance categories. The ANOVA was followed by Tukey multiple comparisons to determine which distance categories differed. Discrete distance categories were used for this analysis because the accuracy of defining redd location was poor (i.e., measured at the segment scale) and the measurement unit for redd location (segment length) varied within and among the rivers. In this case, a regression treating the distances as continuous, accurate measurements for the redd densities is not appropriate. Given the available data, it was more appropriate to divide redd location into three categories; relatively close to a river feature, relatively far from a river feature, and somewhere in between. Relative, in this case, is relative to the range of distances between survey segments and river features that were measured within the four rivers. These data were split into three categories of roughly equal sample size (i.e., split at the 33.3% and 66.7% quantiles). The SRDs within each distance group were not normally distributed (i.e., showed some positive skew), and the log-transformation was not successful in approximating normality. Therefore, a non-parametric rankit transformation was employed (Conover 1980) for the ANOVA.

RESULTS

IDENTIFYING THE SPATIAL STRUCTURE OF RIVERINE HABITATS

Lower Snoqualmie River

General River Basin Characteristics

The Snoqualmie River drains an area of approximately 1,740 km^2 of the Cascade Mountains located due east of Seattle, Washington. Elevations range from less than 10 m near the confluence of the Skykomish River to approximately 1,500 m in the headwaters along the crest of the Cascade Mountains. The Snoqualmie channel network comprises three major forks, the North, Middle, and South Forks located upstream of Snoqualmie Falls. Major tributaries located below Snoqualmie Falls include the Tokul, Raging, and Tolt rivers (Figure 3). The average channel gradient below Snoqualmie Falls (the segment studied in this analysis) is 0.046% (Figure 4).

Valley Segment Characteristics

The valley of the Snoqualmie River is relatively unconstrained between Snoqualmie Falls (the upstream end of the study segment) and the mouth of the Tolt River (Figures 5 and 6). The valley containing the Snoqualmie River narrows below the Tolt River for approximately 8 km before widening upstream of the confluence of Harris Creek. The Snoqualmie again narrows for 6 km downstream of Ames Creek (Figure 5). Valley narrowing may be a consequence of long-term incision into relatively resistant glacial outwash deposits. Despite the variation in valley widths shown in Figure 5, there are no prominent bedrock canyons in the Snoqualmie River between Snoqualmie Falls and the confluence of the Skykomish River. Consequently, there are no abrupt transitions between canyons and unconstrained segments that would generate large deposits of gravel at either the upstream or downstream ends of canyons.

Network and Tributary Junction Characteristics

A logistic regression equation (Chapter 2, Figure 5) was used to predict which tributary junctions could impact the morphology of the lower Snoqualmie River (Benda et al. submitted). Impacts to channel morphology could include coarsening in channel substrates and gradient steepening downstream and reductions of channel gradient, substrate fining, floodplain widening, and increased occurrence of side channels upstream of confluences. Such changes in channel morphology could also impact the occurrence and abundance of hyporheic flow. These unique morphological conditions at junctions could influence the spatial distribution of spawning Chinook salmon. Predictions take the form of probabilities of likely changes and reflect ratios of tributary to mainstem drainage areas. For example, a probability of 0.5 corresponds to a tributary to mainstem drainage area ratio of 0.01 while a 0.9 probability corresponds to a ratio of approximately 0.2.
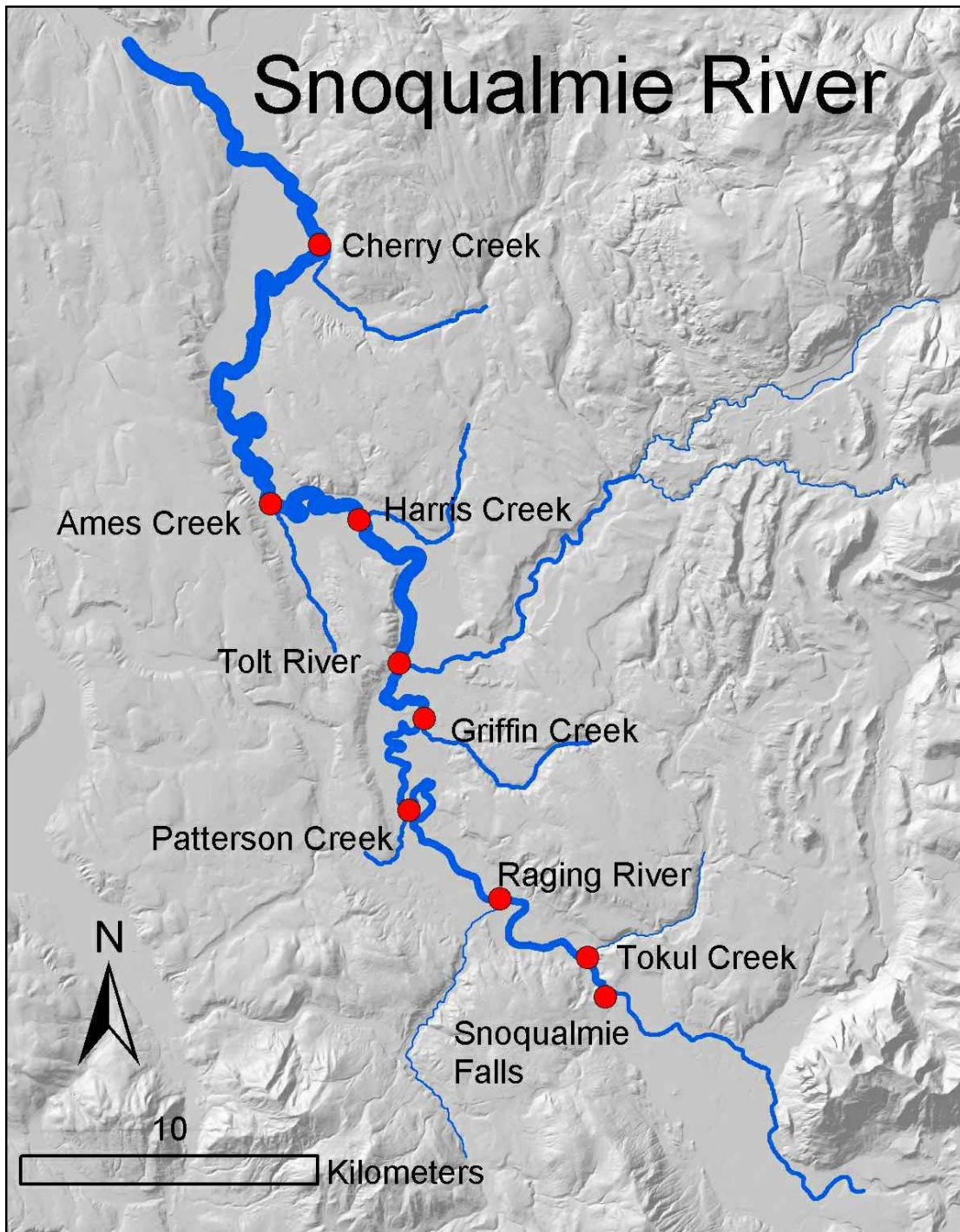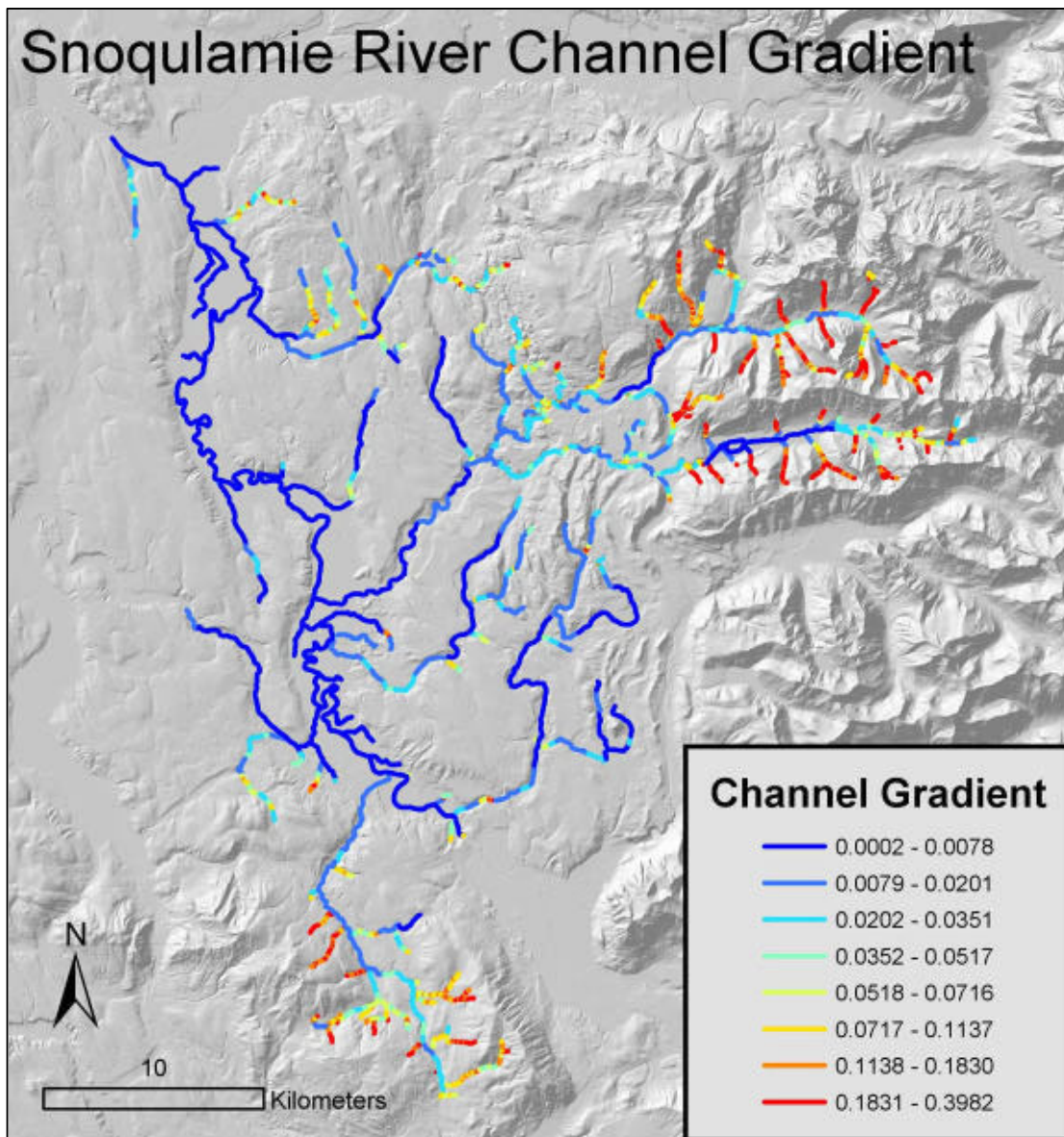
Figure 3. Snoqualmie location map.

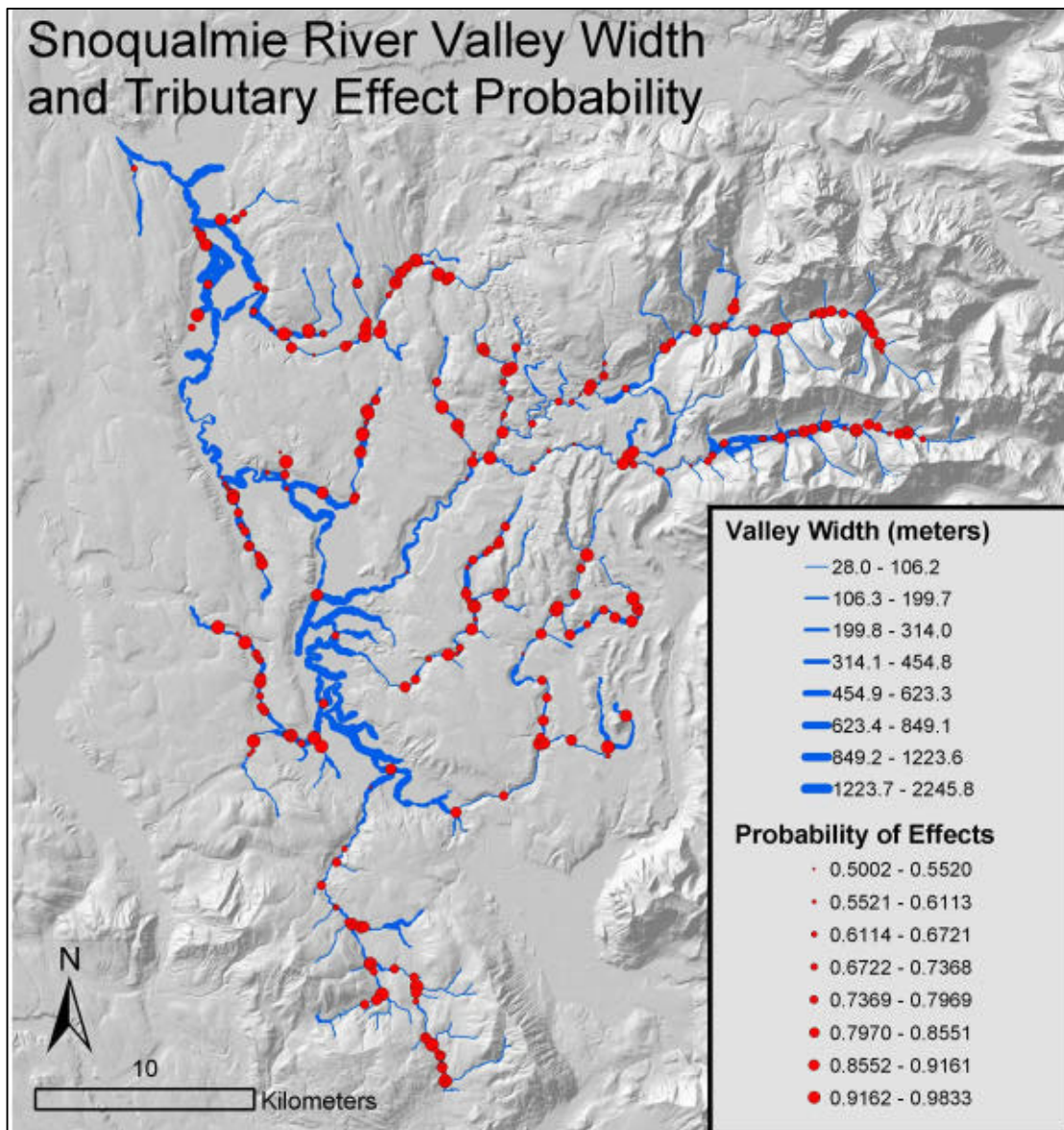**Figure 4.   Snoqualmie gradient map.**

Figure 5.   Snoqualmie valley segment and confluence map.
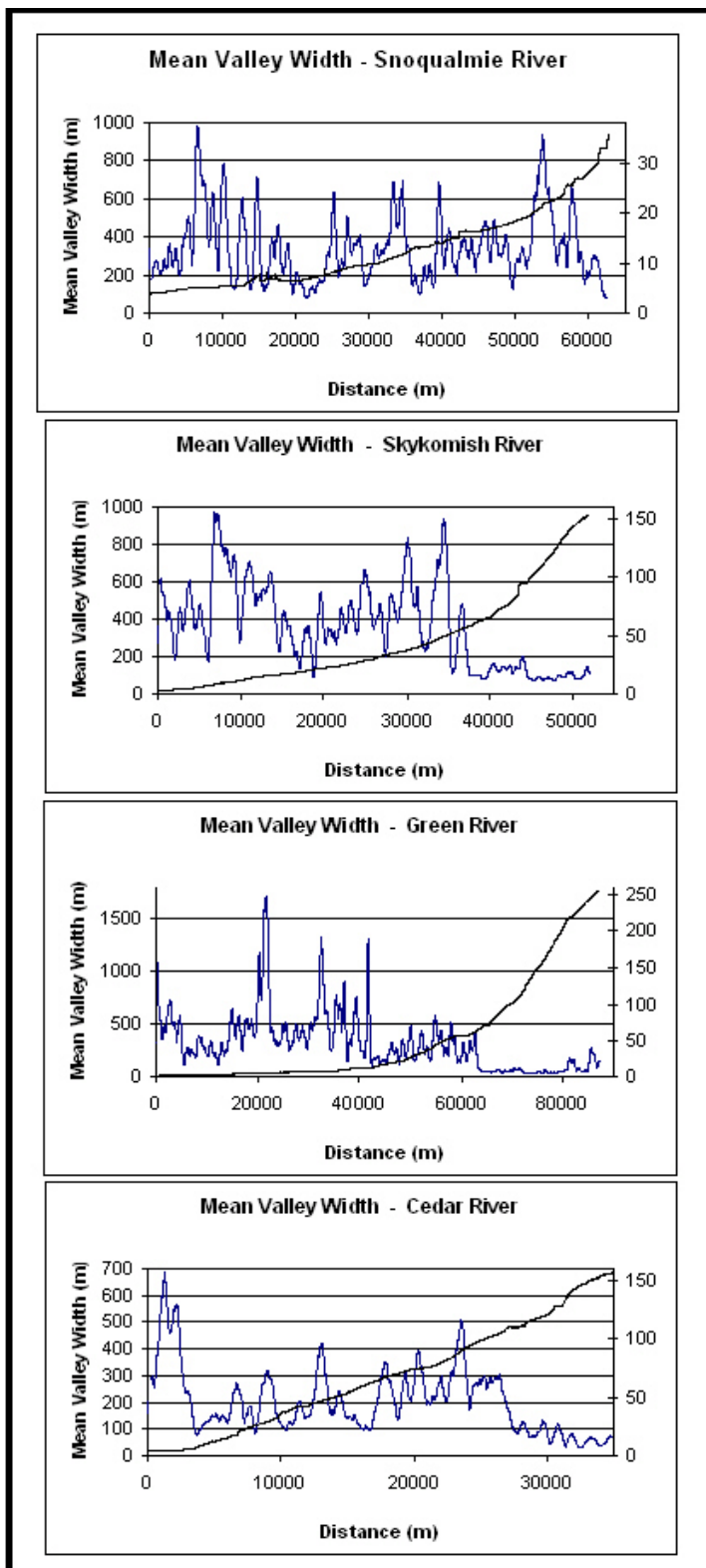
Figure 6. Longitudinal plots of valley widths and channel elevation for the four study rivers.

Previous studies of tributary junction effects have indicated that drainage area ratios generally greater than 0.1 are associated with tributary junction effects (Rhoads 1987). Using this as a guide, we predict that a drainage area ratio of 0.05, corresponding to a probability of approximately 0.75 (e.g., Chapter 2, Figure 5), could lead to tributary confluences impacting the mainstem Snoqualmie River. Tributaries with a probability of greater than or equal to 0.75 that could potentially impact the Snoqualmie River include Cherry (P = 0.76), Tolt (P = 0.92), Raging (P = 0.84), and Tokul (P = 0.85) systems (Figure 5, Table 2). However, Cherry Creek is an underfit stream occupying a drainage basin developed during the last glacial epoch approximately 10,000 years ago (Booth et al. 2003). Consequently, the tributary junction prediction is not valid for Cherry Creek and was not used in this analysis.

If the Tolt, Raging, and Tokul systems affect the morphology of the Lower Snoqualmie River, we predict that Chinook spawning habitats will reflect a spatial structure organized by the distance between the three major tributaries. The distances between the tributaries, starting from downstream, are 11.3 mi (18.1 km) and 3.4 mi (5.4 km), respectively. Hence, Chinook habitats may reflect a spatial scale of variation on the order of 5 to 20 km. Undoubtedly, smaller scale structures should also exist driven by pool-riffle sequences in channel meanders and perhaps by log jams. Because of the use of DEMs, the fine scale structure of Chinook spawning habitat was not verified.

Other Data

The sizes of substrates in the Lower Snoqualmie River were measured by Booth et al. (1991) every 0.5 to 1.0 RM (0.8 to 1.6 km) on point bars from Snoqualmie Falls to the confluence of the Skykomish River. According to field observations and sediment transport modeling, only medium sand (0.3 mm) is transported over Snoqualmie Falls. Bedload originating from the North, Middle, and South forks remains in large depositional zones at the confluences of those rivers (Booth et al. 1991). Consequently, the Snoqualmie River immediately below the falls is supply limited and dominated by bedrock. Each of the three major tributaries located below the falls, Tokul, Raging, and Tolt, contributes significant bedload to the Snoqualmie River, resulting in an abrupt increase in substrate size (from sand to cobble and gravels at and below the junctions) that persists for approximately 2 to 7 mi (average 5 mi [8 km]) downstream of those tributaries (Figure 7). The size (length) of the zones of increased bed particle size is governed in part by the volume of bedload emanating from each of the tributaries and the sediment transport ability of the Snoqualmie River for the supplied bedload. The large bedload deposited into the Snoqualmie from the tributaries is not transported far and remains in place in permanent depositional zones below tributaries, slowly weathering in place to smaller size clasts (Booth et al. 1991).

The analysis of channel grain sizes below Snoqualmie Falls substantiates the predictions made by the network model (e.g., Figure 5) in which the Tokul, Raging, and Tolt rivers were identified as having a high potential for affecting the morphology of the mainstem river. Because of the sediment impoverished state of the Lower Snoqualmie (i.e., little bedload is transported over the falls), the effects of the three major tributaries are magnified, specifically local increases in substrate size downstream of the confluences.

Table 2. Location of river features in the four study rivers, including tributary basin size, size ratio, and effect size. The * indicates P values associated with segments that have high redd density.

| River	Feature Name	Location (RM)	Subbasin Area (km^2)	Mainstem Area (km^2)	Subbasin Size Ratio	Prob. of Effect (P)
Skykomish	Snoqualmie R.	20.5	1794	2075	0.86	0.97
	Woods Cr.	25.1	167	2093	0.08	0.84
	Elwell Cr.	31.8	56	1896	0.03	0.69
	Sultan R.	34.4	271	1595	0.17	0.91*
	Wallace R.	35.7	160	1456	0.11	0.87*
	Proctor Cr.	44.5	28	1352	0.02	0.62
	Canyon mouth	42.0	---	---	---	---
	N. Fk. Sky. R.	49.6	380	932	0.41	0.95*
	Sunset Falls	51.5	---	---	---	---
Snoqualmie	Cherry Cr.	6.7	75	1662	0.05	0.76
	Ames Cr.	17.0	19	1611	0.01	0.50
	Harris Cr.	21.3	29	1569	0.02	0.60
	Tolt R.	24.9	251	1297	0.19	0.92*
	Griffin Cr.	27.2	45	1236	0.04	0.73
	Patterson Cr.	31.2	48	1179	0.04	0.75
	Raging R.	36.2	85	1080	0.08	0.84*
	Tokul Cr.	39.6	85	979	0.09	0.85*
	Snoqualmie Falls	40.3	---	---	---	---
Cedar	Unknown	1.0	7	453	0.02	0.56
	Molasses Cr.	4.1	5	430	0.01	0.51
	Madsen Cr.	4.5	5	423	0.01	0.51
	Taylor Cr.	13.3	11	377	0.03	0.69
	Peterson Cr.	14.4	12	377	0.03	0.70
	Rock Cr.	18.3	9	356	0.03	0.66
	Cliff retreat 1	18.4	---	---	---	---
	Canyon mouth	18.6	---	---	---	---
	Cliff retreat 2	19.3	---	---	---	---
	Walsh Lk. Div.	20.3	6	346	0.02	0.57
	Cliff retreat 3	20.8	---	---	---	---
	Diversion Dam	22.5	---	---	---	---
Green	Big Soos Cr.	33.7	216	763	0.28	0.94*
	Newaukum Cr.	40.7	81	648	0.13	0.88*
	Landslide	42.6	---	---	---	---
	Canyon mouth	45.3	---	---	---	---
	Landslide	49.7	---	---	---	---
	Canyon head	57.6	---	---	---	---
	Diversion Dam	61.0	---	---	---	---
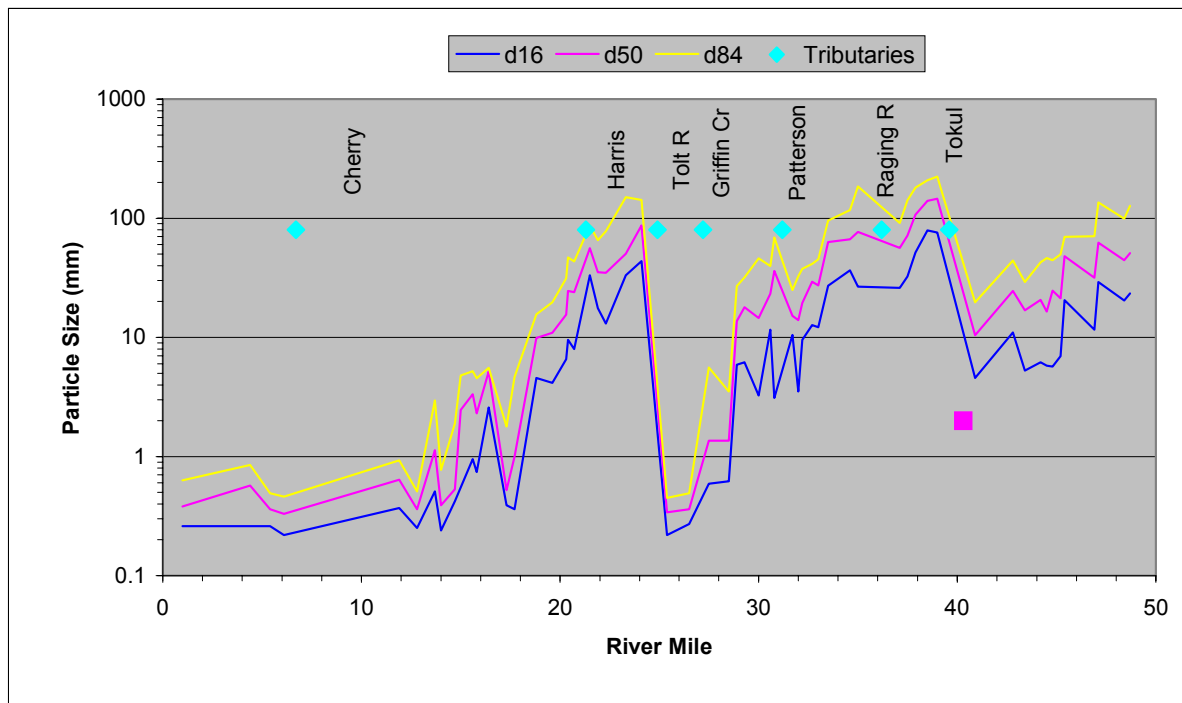
Figure 7.   Surface sediment size in Snoqualmie River (from Booth et al. 1991).

Lower Skykomish River

General River Basin Characteristics

The Skykomish River drains an 842 mi^2 (2070 km^2) area of the Cascade Mountains located east of the Puget Sound. The lower Skykomish River below Sunset Falls contains the major tributaries of the Woods, Sultan, Ellwell/Younger, Wallace, Proctor, and North Fork Skykomish systems (Figure 8). The gradient of the mainstem Skykomish ranges from 0.08% to 0.1% (Figure 9). The upper Skykomish River is predominantly formed in bedrock within relatively narrow valleys. Numerous dikes confine the floodplains in the lowest portions of the river. The Skykomish River basin has an estimated sediment yield of 25 yd^3/mi^2; however, the river segment between the South and North forks is considered supply limited (Collins and Dunne 1987, as cited in Gersib et al. 1999). The reach located between the Wallace River and the Sultan River is characterized by sediment deposition and braiding. The reach between the Sultan River and Woods Creek is considered a transport reach with little net deposition. In contrast, sediment deposition occurs between Woods Creek and the Snoqualmie River confluence, and the river in this section is characterized by frequent channel changes (Collins and Dunne 1987, as cited in Gersib et al. 1999).
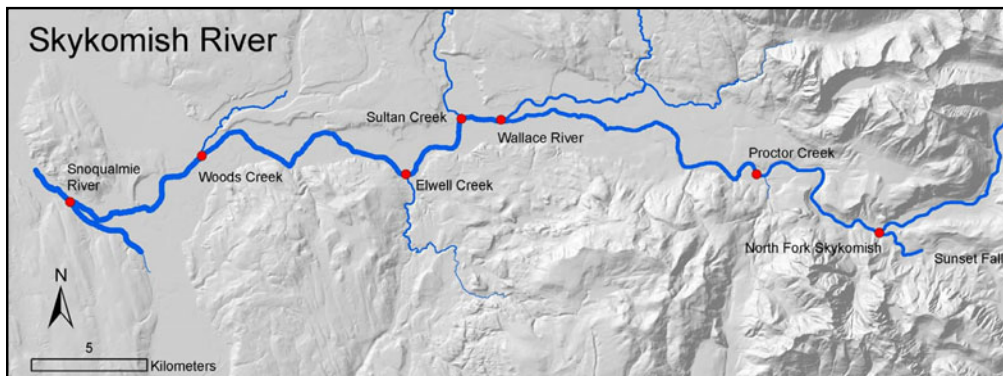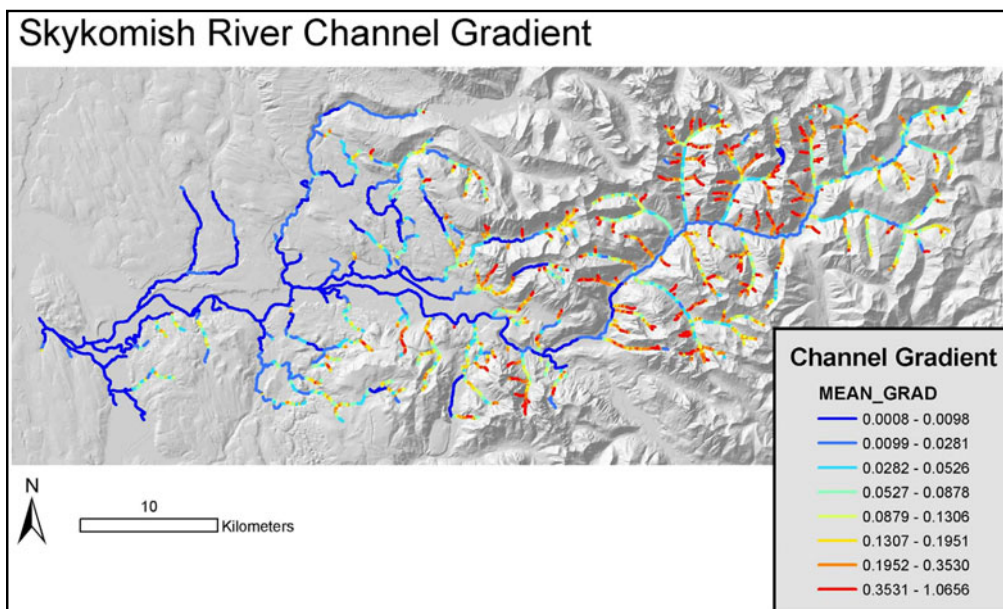
Figure 8.   Skykomish location map.

Figure 9.   Skykomish gradient map.

Valley Segment Characteristics

The width of the Lower Skykomish River valley is relatively uniform below Sunset Falls with the exception of a prominent bedrock canyon located between the falls and the North Fork Skykomish River confluence (Figures 6 and 10). The downstream canyon mouth is located somewhat downstream of the North Fork confluence and hence it was not distinguished from the predicted effect of the North Fork with respect to the structure of riverine habitats. In other words, the potential effects of the canyon mouth and the confluence of the North Fork Skykomish cannot be differentiated based on the models.